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Field evaluation of carrot cultivars for susceptibility to fungal leaf blight diseases in New York

B.K. Gugino, J.E. Carroll[1], T.L. Widmer[2], P. Chen[3], G.S. Abawi*

Department of Plant Pathology, Cornell University, New York State Agricultural Experiment Station (NYSAES), 630 West North St., Geneva, NY 14456, USA

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Abstract

Carrot cultivars grown in New York were evaluated for susceptibility to the fungal leaf blight pathogens *Alternaria dauci* (1999) and *Cercospora carotae* (2000–03) in an experimental field under continuous carrot cultivation since 1996. Replicated plots were established in a randomized complete block design. Plants were rated for disease incidence and severity at regular intervals. Cultivar susceptibility was ranked based on the area under the disease progress curve. An IPM program for carrot leaf blights conducted in growers' fields provided the opportunity to determine the impact susceptibility had on the date the 25% disease incidence threshold was reached to prompt the first fungicide application. Of the cultivars evaluated, Bolero, Carson, Calgary, Ithaca, and Fullback were less susceptible to *A. dauci* whereas, Bolero, Carson, and Bergen were less susceptible to *C. carotae*. Fontana was most susceptible to both fungal leaf blight pathogens. In grower fields less susceptible cultivars reached the 25% threshold later than their more susceptible counterparts. Carrot cultivar susceptibility was incorporated into an IPM program for these diseases.

Keywords: *Alternaria dauci*; Carrot leaf blight; *Cercospora carotae*; Disease resistance; Integrated pest management

1. Introduction

Fungal leaf blights of carrot (*Daucus carota* L. var. *sativus* Hoffm.), caused by *Alternaria dauci* (Kühn) Groves and Skolko and *Cercospora carotae* (Pass.) Solheim, are the major foliar diseases of carrot in New York (Gugino et al., 2004) and in other regions of the world (Ben-Noon et al., 2001; Davis and Rand, 2002). In New York, most of the 599 ha of carrot are grown for the processing market (National Agricultural Statistics Service, 2002) and all are at risk of fungal leaf blight diseases every year (Weingart and Stivers, 1999). Yield losses from leaf blights can be considerable due to a reduction in leaf photosynthetic area and breakage of infected petioles during mechanical harvesting so the roots remain in the ground.

A. dauci lesions are irregularly shaped, brown to black, and commonly found on the margins and tips of older carrot leaflets (Farrar et al., 2004; Hooker, 1944; Strandberg, 1992). *C. carotae* lesions are nearly circular in shape, tan to gray with dark margins, and occur primarily on young leaves (Hooker, 1944; Thomas, 1943). Under a favorable temperature range of 20–28 °C, with an optimum 24 °C, (Carisse and Kushalappa, 1990; Hooker, 1944; Strandberg, 1988), and prolonged hours of leaf wetness (Carisse and Kushalappa, 1990; Carisse and Kushalappa, 1992; Hooker, 1944; Langenberg et al., 1977), infection is promoted and lesions become numerous, expand and coalesce resulting in foliar blight. Both pathogens can also kill leaves by girdling petioles. *A. dauci* and *C. carotae* can be spread through infected or contaminated seed (Maude, 1966; Thomas, 1943), harbored in infected Queen-Anne's-lace (*D. carota* L.) and other *Daucus* spp. (Davis and Rand, 2002; Farr et al., 1989; Thomas, 1943) and survive on crop

*Corresponding author. Tel.: +1 315 787 2374; fax: +1 315 787 2389.
E-mail address: gsa1@cornell.edu (G.S. Abawi).

[1]Current address: New York State Integrated Pest Management, Cornell University, NYSAES, 630 West North St., Geneva, NY 14456, USA.

[2]Current address: USDA-ARS, Foreign Disease and Weed Science Research Unit, Fort Detrick, MD 21702, USA.

[3]Current address: Department of Plant Pathology, National Chung-Hsing University, 250 Kuo Kuang Rd., Taichung, Taiwan 402, ROC.

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residue (Pryor, 2002; Thomas, 1943). The rate of spread of these pathogens in the field depends on the initial level of inoculum, air temperature, leaf wetness duration, and host susceptibility (Aguilar et al., 1986; Carisse and Kushalappa, 1990; Gillespie and Sutton, 1979; Pryor, 2002). Considerable information is available on the epidemiology and forecasting of carrot leaf blights (Abraham et al., 1995; Carisse and Kushalappa, 1990; Gillespie and Sutton, 1979; Langenberg et al., 1977), though management still depends on the frequent application of fungicides. In New York, chlorothalonil is the most commonly used (Weingart et al., 1996) and is an effective fungicide (Abawi and Ludwig, 2003; Abawi and Ludwig, 2004; Carroll et al., 2002; Gugino et al., 2005).

Less susceptible cultivars can delay the onset of disease symptoms, reduce the rate of pathogen spread, and slow the progress of an epidemic (Fry, 1982), potentially minimizing the need for fungicide applications. Prior to the recent development of an IPM program for fungal leaf blights, carrot growers in New York would apply up to eight fungicide sprays during the growing season to protect the crop from leaf blights. Sources of resistance to *A. dauci* (Simon and Strandberg, 1998; Strandberg et al., 1972) and differences in cultivar reactions to leaf blights have been reported previously (Rogers et al., 2002, 2003, 2004), but limited information was available on the reaction of carrot cultivars grown commercially in New York. The identification of commercially available and regionally adapted cultivars with less susceptibility to fungal leaf blight diseases will enable New York growers to more effectively manage fungal leaf blight diseases. Field experiments were conducted to evaluate the susceptibility of commercially grown carrot cultivars to fungal leaf blight diseases and determine the impact cultivar susceptibility level has on disease progress. An IPM program for carrot leaf blights being conducted concurrently in commercial growers' fields (Carroll et al., 2003; Chen et al., 2003) provided the opportunity to determine the impact cultivar susceptibility had on when the 25% disease incidence threshold was reached to prompt the first fungicide application for those cultivars in common to both studies. A preliminary report of this research has been published (Gugino and Abawi, 2005).

2. Materials and methods

2.1. Research trial design and maintenance

In an experimental field of the NYSAES Vegetable Research Farm in Geneva, NY, 19, 21, 10, 5, and 5 commercial slicing and dicing carrot cultivars were planted in 1999, 2000, 2001, 2002, and 2003, respectively, and monitored for the development of leaf blight symptoms. Plots of each cultivar, listed in Table 1, consisted of four 3-m-long rows. Each plot was replicated five times (1999–2002) or four times (2003) in a randomized complete block design. In 1999, all between-plot rows and the two outer border rows were planted with the cultivar Eagle (known to be susceptible) and inoculated by placing *Alternaria*-infected leaves in these rows. In 2000 and 2001, only the two outside border rows were planted to Eagle or the susceptible cv. Fontana, respectively. In 2002 and 2003, border rows of a susceptible cultivar were not planted. From 2000 to 2003, only *Cercospora* leaf blight occurred in the experimental field.

In 1999 and 2000, carrot seed was planted manually at a density of 200 seeds per 3 m of row. Rows were planted using a hand hoe, seeds were distributed and then covered with soil. A two-row tractor-drawn vacuum seeder (A.T.I., Inc. Monosam, Lenexa, KS) was used in subsequent years. Carrot seeds of cultivars tested were obtained annually from various seed companies. The cultivars evaluated reflected the predominant cultivars commercially available in New York. To promote leaf blight infection and prevent drought stress, the plot area was overhead irrigated as needed. All other maintenance practices were employed according to standard New York commercial production guidelines. Plots were sprayed with the insecticide esfenvalerate (Asana®XL, DuPont Crop Protection, Wilmington, DE) to manage Aster leafhopper (*Macrosteles quadrilineatus* Forbes) early in the season and weeds were managed with cultivation and applications of linuron (Lorox® or Linex®, DuPont Crop Protection, Wilmington, DE). No fungicides were applied to these research trials. During the course of these trials, aside from the fungal leaf blight diseases, no other pests increased to a level that impacted carrot production at this location.

2.2. Disease assessment

In 1999, the middle two rows of each cultivar plot were rated for disease incidence (the presence or absence of one or more lesions) each week by examining five leaves from five adjacent plants in 10 random sites within each plot. From 2000 to 2003, the middle two rows of each cultivar plot were rated for disease incidence every 2 weeks by examining five leaves from five adjacent plants at five random sites within each plot for a total of 25 leaves per plot. In all years, disease severity was assessed for each plot on a scale of 1–9 based on the percentage of leaf area symptomatic (1 = 0% tissues symptomatic, 2 = up to 1%, 3 = 2–5%, 4 = 6–10%, 5 = 11–20%, 6 = 21–30%, 7 = 31–40%, 8 = 41–50%, and 9 = over 50%). Comparisons of cultivar susceptibility within each year were based on differences in the area under the disease progress curve (AUDPC) calculated from the severity ratings for each cultivar.

2.3. Evaluation in commercial fields

From 1999 through 2004, commercial growers' fields in central and western New York were scouted once per week for leaf blight disease from mid-June through mid-September. Growers in New York typically plant fields to

Table 1
Relative carrot cultivar susceptibility to leaf blight caused by *Alternaria dauci* in 1999 and *Cercospora carotae* in 2000–03 as determined in randomized complete block design experimental field plots, Geneva, NY

1999		2000		2001		2002		2003	
Cultivar	AUDPC[a,b]	Cultivar	AUDPC	Cultivar	AUDPC	Cultivar	AUDPC	Cultivar	AUDPC
Bolero	112.6 a	Bolero	209.5 a	Bolero	278.2 a	Carson	113.0 a	Bergen	248.8 a
Carson	115.5 a	Neal	219.7 ab	Carson	291.1 a	Bergen	128.9 a	Bolero	265.5 a
Calgary	131.1 ab	Bergen	245.1 abc	Bergen	326.8 b	Bolero	150.1 b	Carson	276.3 ab
Ithaca	133.7 ab	Calgary	246.8 abc	Newport	329.2 b	Recoleta	167.8 b	Recoleta	305.3 bc
Fullback	138.3 abc	Carson	252.3 abcd	Bristol	340.7 b	Fontana	264.9 c	Fontana	325.3 c
Neal	152.3 bcd	Boomer	259.9 abcd	Eagle	359.1 bc				
Boomer	161.0 bcde	Bristol	269.2 bcde	Idaho	374.5 cd				
Idaho	170.0 cdef	Ithaca	270.7 bcde	Canada	376.6 cd				
Canada '98[c]	172.4 def	Fullback	280.3 cdef	Kamaran	397.0 d				
Canada '99[c]	173.8 def	Indiana	282.4 cdef	Fontana	495.7 e				
Oranza	187.7 efg	Idaho	286.6 cdef						
Eagle	189.1 efg	Canada	288.5 cdef						
Bergen	193.6 fg	Newport	288.8 cdef						
Indiana	194.2 fg	Eagle	296.5 cdef						
Goliath	214.2 gh	Nevis	306.5 defg						
Kamaran	230.0 hi	Nepal	324.1 efg						
Newport	236.5 hi	Kamaran	324.4 efg						
Napa	249.5 i	Oranza	332.3 fg						
Nevis	253.9 i	Goliath	353.5 g						
Fontana	300.7 j	Napa	353.8 g						
		Fontana	416.9 h						

[a]$\text{AUDPC} = \sum_{i<n}[(R_{i+1} + R_i)/2][t_{i+1} - t_i]$, where R_i = disease severity rating (1 = 0% tissues symptomatic, 2 = up to 1%, 3 = 2–5%, 4 = 6–10%, 5 = 11–20%, 6 = 21–30%, 7 = 31–40%, 8 = 41–50%, and 9 = over 50%) at the ith observation, t_i = time (days) since the previous rating at the ith observation, and n = total number of observations.

[b]Mean separations followed by the same letter within each year are not significantly different according to Fisher's least-significant difference test at $P = 0.05$ (for 1999–2002, $P<0.0001$ and 2003, $P = 0.0014$).

[c]Seed of the cultivar 'Canada' was evaluated from seed lots collected in two different years, 1998 and 1999.

more than one carrot cultivar, with each cultivar occupying a large block of the field (i.e., half or a third of all rows). Fields in our study contained 1–4 cultivar blocks. Every week each cultivar was scouted along a 'V'-shaped transect at 10 regularly spaced locations. At each location, five leaves from five adjacent plants were rated for disease incidence and severity. Growers were advised to delay applying the first fungicide application until the respective carrot cultivar reached the 25% disease incidence threshold (11–12 of the 50 leaves observed are symptomatic) (Gillespie and Sutton, 1979; Sutton and Gillespie, 1979). For fields with more than one cultivar, the relative susceptibility rating obtained for those cultivars in our experimental field plots were compared with the dates each cultivar reached the 25% disease incidence threshold.

2.4. Statistical analysis

The AUDPC values were calculated for the individual cultivars in the research trials by the following formula: $\text{AUDPC} = \sum_{i<n}[(R_{i+1} + R_i)/2][t_{i+1} - t_i]$, where R_i is the disease severity rating at the ith observation, t_i the time (days) since the previous rating at the ith observation, and n the total number of observations (Shaner and Finney, 1977). The AUDPC values were subjected to analysis of variance (ANOVA) to evaluate differences between cultivar within each year. Mean comparisons were conducted using Fisher's protected least-significant difference (LSD) test ($P \leqslant 0.05$) (SAS 9.0, SAS Institute, Cary, NC).

3. Results

3.1. Research trials

Cultivar ranking based on AUDPC value is given in Table 1 for each year of the study. None of the cultivars evaluated was completely resistant (i.e., free of visible symptoms) to either leaf blight pathogen. Leaf blight was caused by *A. dauci* in 1999 and by *C. carotae* in 2000, 2001, 2002, and 2003. The differences obtained for some cultivars in their susceptibility ranking between 1999 and that of subsequent years reflected the shift in pathogen between those years; a shift also observed in commercial fields. For example, based on the AUDPC values, Bergen was among the cultivars moderately susceptible (MS) to *Alternaria* leaf blight evaluated in 1999, but it was consistently among the least susceptible (LS) to *Cercospora* leaf blight in subsequent years. Newport was also susceptible to *A. dauci* but only MS to *C. carotae*. Goliath and Oranza were MS to *A. dauci* and susceptible to *C. carotae*. Ithaca and Fullback proved to be LS to *Alternaria* and MS to *Cercospora*. Idaho, Canada, Eagle, and Indiana were MS and Kamaran, Napa, and Nevis were susceptible to both leaf blight pathogens. Interestingly, Bolero, Carson, Calgary, and Neal were consistently among the LS to both fungal leaf blight pathogens. Among the cultivars planted in all years, even under-varying levels of disease pressure and differing environmental conditions, Bolero and Carson consistently proved to be LS to fungal leaf blight, while Fontana was consistently the most susceptible.

3.2. Evaluation in commercial fields

The relative differences in susceptibility of carrot cultivars observed in the research trials was also observed in commercial production fields in New York from 1999 to 2004 during a carrot IPM demonstration research project. It was noted that the less susceptible cultivars often reached the 25% disease incidence threshold later than the more susceptible cultivars growing in the same field (Table 2). In a field scouted in 1999, LS Carson never reached the 25% threshold, while MS Indiana reached the threshold on 20 July. In 2000, Eagle (MS) and Canada (MS) reached the 25% threshold 2 and 3 weeks, respectively, earlier than Carson (LS) in two separate fields. The first fungicide spray was recommended for susceptible (S) Fontana 3 weeks earlier than Canada (MS) in a field scouted in 2001. Similar results were obtained in 2003, with Eagle (MS) and Canada (MS) reaching the 25% threshold for prompting the first fungicide application 2 weeks earlier than Carson (LS) growing in the same field.

In 2002, Bergen, a less susceptible cultivar to *Cercospora* leaf blight, reached the 25% disease incidence threshold earlier than Carson (LS), Canada (MS), and Recoleta (MS) (Fig. 1A), and was sprayed by the grower one additional time. At the end of the season, Bergen along with Carson had lower AUDPC values, 47.2 and 57.4, respectively, compared to Recoleta and Canada, 130.2 and 111.6, respectively. Both *A. dauci* and *C. carotae* were present in the field, though *Cercospora* leaf blight was the most prevalent disease. Throughout the latter part of the season, disease severity ratings for Carson and Bergen were at or below a rating of 2 (< 1% leaf surface symptomatic) and much lower than the ratings for Recoleta and Canada, which ranged between 4 and 5 (6–20% leaf surface symptomatic) (Fig. 1B).

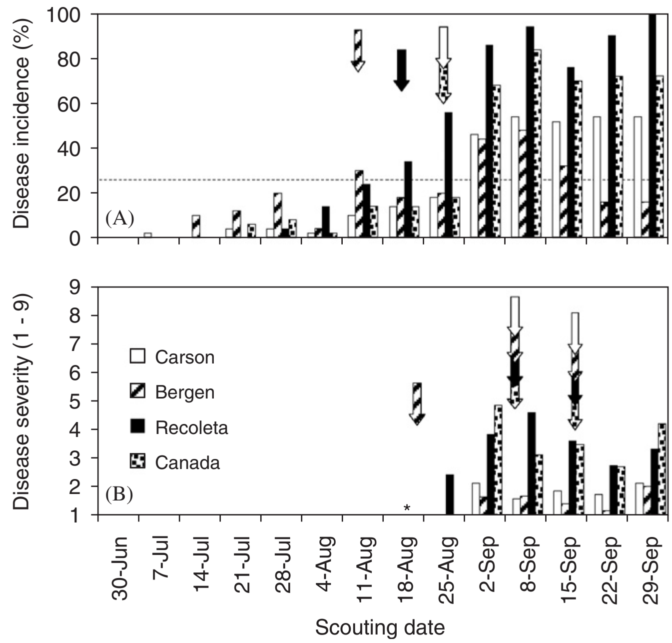

Fig. 1. Fungal leaf blight disease incidence (A) and severity (B) in 2002 for a commercial field with four carrot cultivars, Carson (less susceptible), Bergen (less susceptible to *Cercospora*), Recoleta (moderately susceptible), and Canada (moderately susceptible). Each cultivar in the field was scouted weekly in a 'V' transect and disease incidence (A) recorded. The dashed line (Fig. 1A) shows the 25% disease incidence threshold that prompts the first fungicide application. After the 25% threshold was reached, disease severity (B) was recorded weekly on a scale of 1–9 (1 = 0% tissues symptomatic, 2 = up to 1%, 3 = 2–5%, 4 = 6–10%, 5 = 11–20%, 6 = 21–30%, 7 = 31–40%, 8 = 41–50%, and 9 = over 50%). Arrows indicate when a fungicide application was applied by the grower on the correspondingly shaded cultivar based on disease incidence (A) and increases in disease severity (B) (i.e., Bergen received four fungicide applications, one based on disease incidence and three based on disease severity). *Disease severity data not collected on 18 August.

Table 2
Commercial carrot fields scouted weekly for fungal leaf blights where cultivars rated as more susceptible in the research trials reached the 25% leaf blight disease incidence threshold before cultivars rated as less susceptible (Carson)

Year	Location	Variety	Pathogen[a]	Date threshold[b]
1999	Genesee County	Carson	*A. dauci*	Not reached
		Eagle		3 August
		Newport		3 August
		Indiana		20 July
2000	Yates County 1	Carson	*C. carotae*	1 August
		Eagle		19 July
	Yates County 3	Carson	*C. carotae*	8 August
		Canada		19 July
2001	Yates County	Canada	*C. carotae*	30 July
		Fontana		9 July
	Orleans County	Carson	*C. carotae*	27 August
		Kamaran		7 August
2003	Yates County	Carson	*C. carotae*	18 August
		Canada		4 August
		Eagle		4 August

[a] *A. dauci* = *Alternaria dauci*; *C. carotae* = *Cercospora carotae*.
[b] Date the cultivar reached the 25% leaf blight disease incidence threshold for applying the first fungicide spray. No fungicide sprays were applied prior to threshold.

4. Discussion

Our study of carrot susceptibility to leaf blight is the first reported for the slicing and dicing cultivars commercially grown in New York. However, screening carrot cultivar reactions to *Alternaria* leaf blight and *Cercospora* leaf blight and identifying sources of resistance alleles have been conducted in other carrot growing regions (Aguilar et al., 1986; Rogers et al., 2002, 2003, 2004; Simon and Strandberg, 1998; Strandberg et al., 1972). The results obtained in this study were similar for the cultivars in common with studies conducted in Wisconsin (Rogers et al., 2002, 2003, 2004). Our results enumerated the relative differences in the susceptibility of several commercially grown carrot cultivars in New York over multiple growing seasons to *C. cerospora*; currently the predominant leaf blight pathogen is observed in New York. In addition, we were able to document the practical impact of host resistance on a carrot leaf blight IPM program we conducted over this same time period in commercial carrot production fields in New York.

Differences in weather conditions and overwintering inoculum most likely impacted the differences in the range of AUDPC values between years that were obtained for *Cercospora* leaf blight. Despite these differences, the relative *Cercospora* leaf blight susceptibility ranking for the cultivars remained essentially the same in years 2000–03. Screening cultivars for *Alternaria* leaf blight was only possible in 1 year because of reliance on natural infection. Although we "seeded" the plots in 1999 with *Alternaria*-infected leaves, these leaves and those of the plant debris left in the field did not serve to carry the disease over to the next year. *Cercospora* leaf blight infection occurred from 2000 to 2003 possibly becoming established from seed-borne inoculum, from infected Queen-Anne's-lace near the plot, or through cross-contamination of the plot from adjacent carrot research plots. It is interesting to note that most commercial carrot fields in 1999 were infected with *Alternaria* leaf blight, while from 2000 to the present, *Cercospora* leaf blight has been more commonly identified.

We have shown that the less susceptible cultivars, such as Carson, can be used in commercial production as a significant part of an IPM program aimed at reducing the number of fungicide applications. The planting of less susceptible cultivars is a strategy frequently incorporated into IPM programs for many different crops ranging from potato (Elad et al., 1980) to deciduous fruit trees (Sutton, 1996). Now that we have elucidated the relative level of susceptibility to fungal leaf blights of carrot cultivars grown commercially in New York, informed choices can be made to incorporate cultivar reaction into an IPM program for carrot leaf blights (Gillespie and Sutton, 1979; Sutton and Gillespie, 1979) that has been validated in New York (Carroll et al., 2003; Chen et al., 2003; Gugino and Abawi, 2005). We have shown that the level of susceptibility can slow the leaf blight epidemic progress and delay the date when a carrot cultivar reaches the 25% disease incidence threshold for applying the first fungicide spray. Results obtained indicate that the number of fungicide sprays required to manage fungal leaf blight diseases may be reduced by one or possibly more sprays. However, other factors play potentially greater roles in the IPM of carrot leaf blights, including crop rotation and weather conditions. In a field that had no history of carrot cultivation and dry weather conditions, the susceptible cultivar Kamaran never reached the 25% incidence threshold for either pathogen. In another field that was overhead irrigated and had been in continuous carrot cultivation for 2 years, Bolero (LS), Bergen (MS), and Kamaran (S) all reached threshold for *Alternaria* leaf blight on the same date, very early in the growing season.

Although these other factors are important in the IPM of carrot leaf blights, without foreknowledge of the contribution cultivar reaction makes in the disease epidemic, it is more difficult to determine the relative contribution of other factors. Therefore, leaf blight resistance screening of new carrot cultivars and germplasm under field conditions will continue to be an important step in furthering the management of these diseases. We have provided data on the level of susceptibility of several carrot cultivars commercially grown in New York to enable growers to more effectively manage fungal leaf blight diseases on carrots.

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